Automated Verification of Mesoscale Forecasts using Image Processing Techniques

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LONG-TERM GOALS

The APL atmospheric sciences group is working to improve forecaster performance at Navy operational weather forecast detachments afloat and ashore. This work encompasses broad research and technology development in areas of visualization, human factors, human-machine interaction, and model and forecast verification with an emphasis on mesoscale ensembles and visualization of uncertainty. The verification effort's long-term goal is to develop an automated, objective verification technique for assessment of very high-resolution mesoscale predictions which accurately accounts for spatially or temporally misplaced features, false alarms and misses (Brown 2002).

OBJECTIVES

The overall objective of this effort is to develop a highly automated, rapid, mesoscale numerical weather prediction (NWP) verification tool for use by forecasters and model developers. The verification technique should consider distortion errors (phase/timing, rotation, and stretching) as well as the normal amplitude errors. It is intended to test the verification tool on the University of Washington Short Range Ensemble Forecast System (SREF) and with a version of the Navy COAMPS model to be implemented at APL.

APPROACH

The verification technique of Van Galen (1970) and Hoffman, et. al., (1995) will be implemented as a rapid, automated, web-enabled forecaster and model developer tool. This technique, originally intended for synoptic-scale features, will be tested on mesoscale predictions of a number of parameters in an attempt to separate model forecast errors into amplitude, phase, rotation, and distortion components for better evaluation of mesoscale model capabilities. In order to improve processing time, image motion processing techniques (Chan, 1993; Lim and Ho, 1998) will be implemented and tested for potential acceleration of the verification routine. The verification tool will be used to evaluate the

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14. ABSTRACT
The APL atmospheric sciences group is working to improve forecaster performance at Navy operational weather forecast detachments afloat and ashore. This work encompasses broad research and technology development in areas of visualization, human factors, human-machine interaction, and model and forecast verification with an emphasis on mesoscale ensembles and visualization of uncertainty. The verification effort?s long-term goal is to develop an automated, objective verification technique for assessment of very high-resolution mesoscale predictions which accurately accounts for spatially or temporally misplaced features, false alarms and misses (Brown 2002).

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University of Washington Short Range Mesoscale Ensemble (SREF) performance and also will be tested on an APL version of COAMPS when implemented. As an expansion of this effort, a user-focused cost-loss evaluation will be investigated for better interpretation of component verification (amplitude, phase, rotation, distortion) results. Additional participants include Dr. Caren Marzban added to the effort in FY04 and collaborations with Dr. Cavan Rielly, U. of Minn. and Dr. Jason Nachamkin at the Naval Research Laboratory. Our group has been approached by Dr. Sandra Yuter of UW for applications to satellite cal/val and by Dr. Craig Bishop of NRL for development of model error characteristics for data assimilation. Support of these efforts will require modification of code to allow it to easily accommodate disparate data sources. In order to deal with limitations to the Hoffman technique for discontinuous fields such as precipitation and to deal with multi-scale processes, a variety of statistical techniques are being reviewed for implementation into the MVT framework. These include agglomerative cluster analysis (Marzban and Sandgathe, 2005) and variograms.

WORK COMPLETED

FY2003 progress: The Hoffman (1995) technique for amplitude and phase error was implemented in both MATLAB and web-enabled versions (see figure 1 below) and fully tested on idealized and real model cases. Three image motion processing techniques were implemented in the routine and tested for both acceleration and accuracy. Three methods of error minimization (mean absolute difference (MAD), route mean square error (RMSE) and mean square error (MSE)) were tested both for numerical efficiency and accuracy of localization. In addition, a competing verification technique developed by University of Minnesota was tested on idealized and real cases and a paper is currently in review.

FY2004 progress: A combination of acceleration techniques developed by the motion picture industry for image motion processing were chosen for the final version of the search engine. These techniques, a two-step layered structure algorithm and an inter-block motion algorithm, resulted in approximately 30x acceleration in the verification routine with an error of less than one percent. The web-based verification tool, "Mesoscale Verification Tool" or MVT, was finalized for the UW ensemble system and implemented on the UW Mesoscale Uncertainty Monitor (MUM) for use by local Navy, NWS and other forecasters and scientists. A web-based batch verification tool, the "Automated Mesoscale Verification Tool", or AMVT was implemented for rapidly verifying large data sets including multiple models, multiple parameters and long time series. Both MVT and AMVT incorporate the search acceleration techniques that allow consideration of time and phase errors during verification.

Techniques are being explored to deal with event-based verification, necessary for both verification of precipitation which is discontinuous in areal extent and for verification of extreme events such as a frontal passage. Agglomerative Hierarchical Cluster Analysis (CA) is being tested as a means to automatically group precipitation observations or grid-based predictions into related 'clusters', i.e., unique precipitation events, to allow automated verification. Currently, (Ebert and McBride, 2000 and Du and Mullen, 2000) it is necessary to identify precipitation clusters by hand analysis prior to verification using the Hoffman technique. Using CA we have been able to demonstrate (Marzban and Sandgathe, 2005) a potentially automated means of associating observed and model forecast precipitation events. Last year we reported the selection of mean square error (MSE) as the primary minimization parameter. However, we have found that for extreme events such as frontal passage, the grid-based Hoffman technique is not sufficiently sensitive to capture, uniquely, the phase shift of a very 'sharp' event when it is part of a much broader field. Consequently, we are testing the use of

mean quadratic error (MQE) as the minimization parameter in our search routine. The selection of MQE over MSE highlights the most extreme values and, based on tests to date, appears to easily capture extreme event phase shifts.

FY05 progress: The MVT and AMVT programs have been recoded for efficient and more user-oriented operation. The software has also been expanded to allow input of netCDF files, enabling more flexibility in verifying any gridded model outputs including using the system for satellite image calibration. Portions of these programs are being transitioned into the ONR Visualization of Uncertainty Multidisciplinary University Research Initiative and into the Environmental Visualization (EVIS) portion of the ONR Future Naval Capabilities (FNC) on Knowledge Superiority. The remainder to the CY05 effort will be devoted to analysis of several large ensemble case studies using AMVT and the UW SREF.

A cluster analysis technique (Marzban and Sandgathe, 2005) using agglomerative hierarchical cluster analysis which incorporates both spatial relations and parameter value (e.g. precip amount) has been tested for verification of discontinuous fields such as precipitation. Figure 2 below is an example of CA applied to a precipitation field. This technique was very well received at the Montreal Verification Workshop (Marzban, 2004) and has been recently funded by NSF for rapid transition into the DoD/NOAA/NCAR mesoscale WRF Developmental Testbed Center (DTC).

RESULTS

FY03: The Van Galen/Hoffman technique has been successfully implemented both in MATLAB for further scientific investigation and as a prototype web-based forecaster tool in the UW Mesoscale Uncertainty Monitor (MUM). The MUM is a prototype forecaster aide being developed for testing at NPMOD Whidbey Island. An approximately 30x increase in processing speed in the verification tool has been achieved by implementing a combination of two image motion processing routines and optimizing the computer code functions. In addition, it was determined that MSE error minimization for localization produced the most reliable and accurate verification computation without significantly impacting computational speed.

FY04: The Mesoscale Verification Tool using a two-step layered structure algorithm and an inter-block motion algorithm in combination has been transitioned to the MUM in final form. The Automated Mesoscale Verification Tool, a web-interactive batch verification tool has been developed and tested for use on very large data sets with multiple parameters, great flexibility, and including multi-member ensemble verification. A mean quadratic error algorithm has been tested and implemented as an improved search criterion for extreme event verification and has been incorporated as an option in the AMVT. A cluster analysis technique using agglomerative hierarchical cluster analysis which incorporates both spacial relations and parameter value (i.e. precip amount) has been tested for verification of discontinuous or fields such as precipitation.

FY05: The AMVT and MVT software have been recoded for more efficient and user friendly operation including adding the capability to accept netCDF files. This capability will allow input of any gridded model fields for verification or comparison including satellite and radar image calibration. The agglomerative cluster analysis technique (Marzban and Sandgathe 2005) has been selected by NSF for incorporation into the mesoscale DTC.

IMPACT/APPLICATIONS

Verification systems need to be highly automated in order to rapidly assess large samples of cases; however, they must also be able to correctly evaluate the high frequency, high amplitude signals of mesoscale features. Unfortunately, traditional methods of verification have been shown not to work for mesoscale numerical weather prediction. Simple automated techniques incorrectly assess slight phase or displacement errors, causing smoothed, or ensemble mean forecasts to appear to perform better than a more detailed deterministic forecast, yet they contain less forecast content. Case studies, while more revealing, are too time consuming to assess the large number of cases required for subtle model biases or differences arising from small changes in model algorithms. Mesoscale NWP forecast verification is a critical issue for US Navy operations. More NWP model outputs are becoming available from various sources and it is difficult for management and operational forecasters to choose the appropriate system for each forecast situation. The forecast verification tool will enable more accurate and meaningful evaluation of mesoscale numerical weather prediction systems, especially mesoscale ensemble systems, where large volumes of data are required for accurate assessment and where small prediction distortions or displacements cause significant misinterpretation of verification results. The tool is intended for use both by model developers and by forecasters for quick and more accurate model assessment. The forecaster tool will be implemented as an easy to use web tool.

TRANSITIONS

The MVT has been transitioned to the MUM or Mesoscale Uncertainty Monitor as a test product. It is also being considered by the Environmental Visualization (EVIS) program as a potential web-based user tool and by the NRL as a COAMPS On-scene user tool. The agglomerative cluster analysis technique has been funded by NSF for transition into the DoD/NCAR/NOAA Mesoscale Developmental Test Center (DTC).

RELATED PROJECTS

The University of Washington Multidisciplinary University Research Initiative (MURI) on Integration and Visualization of Multi-Source Information for Mesoscale Meteorology: Statistical and Cognitive Approaches to Visualizing Uncertainty. This project incorporates a number of verification techniques into a forecaster visualization tool and a prototype version of our mesoscale verification tool has been implemented here. The Environmental Visualization (EVIS) effort of the Knowledge Superiority FNC funded by ONR has reviewed the MVT and is planning to test it as a potential user application.

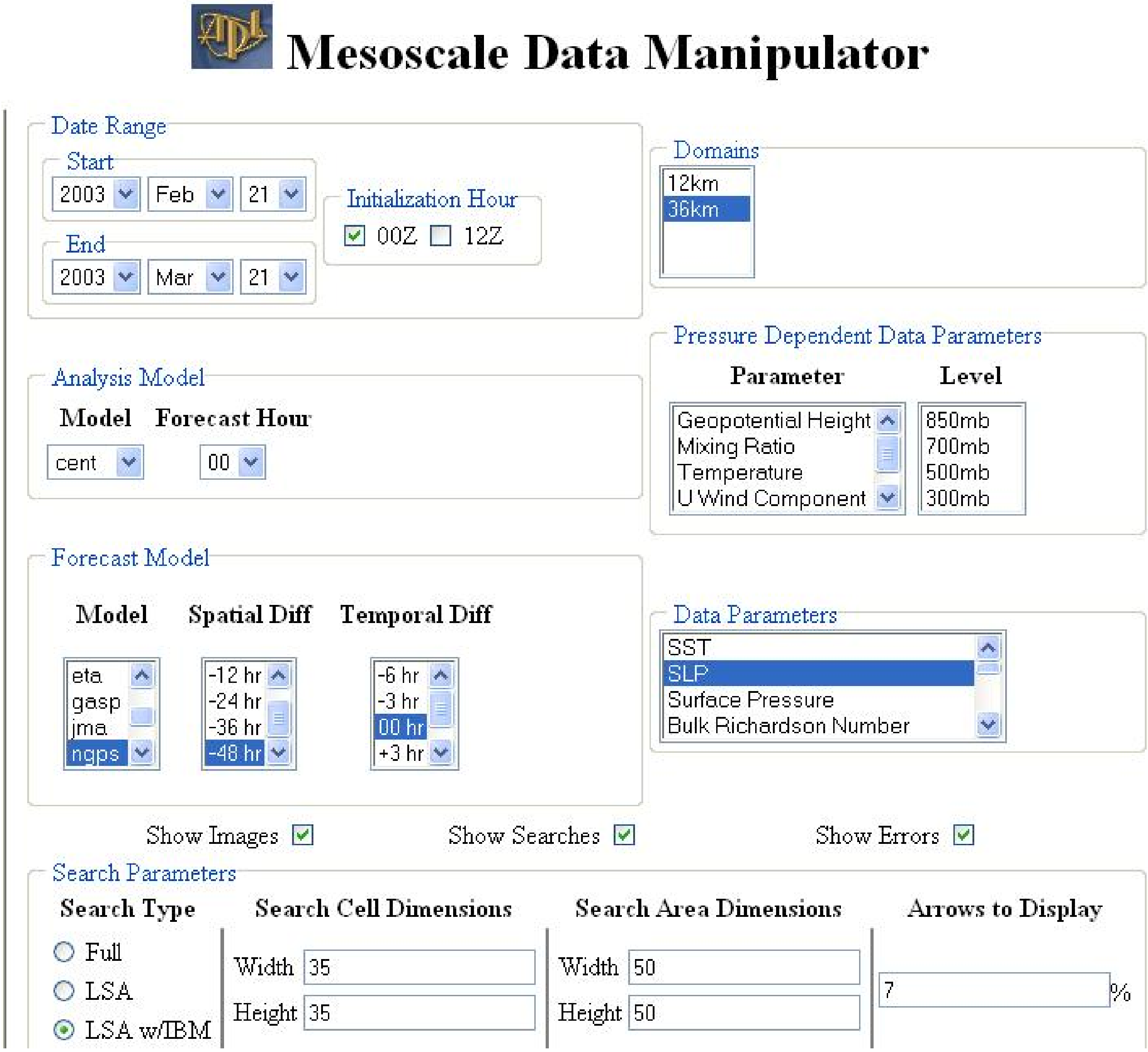

Figure 1. Automated Mesoscale Verification Tool GUI
[Automated Mesoscale Verification Tool (AMVT) Graphical User Interface displaying model and parameter selection for web-based submission of large and/or complex verification of multiple models or multi-member ensembles.]

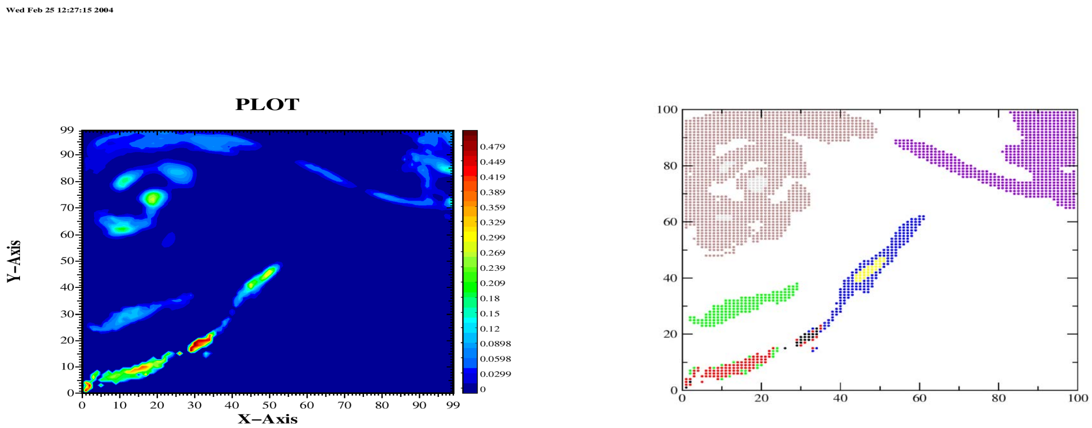

Figure 2. Example of precipitation field decomposed using agglomerative cluster analysis. [The field on the left is a plot of precipitation intensity for the NE Pacific and NW America. The field on the right is the same field indicating clustering of precipitation based on location and intensity.]

REFERENCES

- Brown, B., 2002: Development of an Object-based Diagnostic Approach for QPF Verification. USWRP Science Symposium, April 2002.

- Hoffman, R. N., Z. Liu, J.-F. Louis, and C. Grassotti, 1995: Distortion representation of forecast errors. Mon. Wea. Rev., 123, 2758-2770.

- Ebert, E. E., and J. L. McBride, 2000: Verification of precipitation in weather systems: determination of systematic errors. J. Hydro., 239, 179-202.

- Du, J., and S. L. Mullen, 2000: Removal of Distortion Error from an Ensemble Forecast. Mon. Wea. Rev., 128, 3347-3351.

- Chan, E., 1993: Review of Block Matching Based Motion Estimation Algorithms for Video Compression. CCECE/CCGEI.

- Lim, D.-K., and Y.-S. Ho, 1998: A Fast Block Matching Motion Estimation Algorithm based on Statistical Properties of Object Displacement. IEEE.

- Van Galen, J., 1970: A new method for verifying deterministic predictions of meteorological scalar fields. Tellus, XXII, 32-42.

PUBLICATIONS

- Marzban, C., and S. Sandgathe, 2005: Cluster analysis for verification of precipitation fields. Accepted Wea. Forecasting. (Refereed Journal)

- Reilly, C., P. Price, A. Gelman and S. A. Sandgathe, 2004: Using Image and Curve Registration for Measuring the Goodness of Fit of Spatial and Temporal Predictions. Journal of Biometrics, 60, 954-964. (Refereed Journal)

- Marzban, C., S. Sandgathe, E. Kalnay, 2005: MOS, Perfect Prog, and Reanalysis Data. Accepted Monthly Weather Review. (Refereed Journal)